AD-A123 182 NONLINEAR TRANSIENT ANALYSIS OF LAYERED COMPOSITE PLATES(U) VIRGINIA POLYTECHNIC INST AND STATE UNIV BLACKSBURG DEPT OF E.. J N REDDY JUL 82

UNCLASSIFIED AFOSR-TR82-1063 AFOSR-81-0142 F/G 11/4

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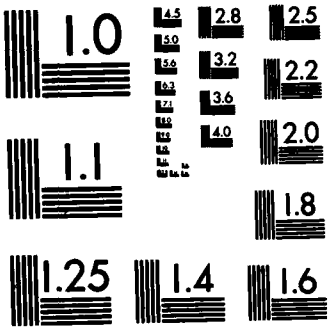

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(2)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
AFOSR-TR- 82-1063	AD-A123 782	

4. TITLE (and Subtitle)
NONLINEAR TRANSIENT ANALYSIS OF LAYERED COMPOSITE PLATES

5. TYPE OF REPORT & PERIOD COVERED
Annual
1 Apr 81 - 15 Jun 82

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
J N REDDY

8. CONTRACT OR GRANT NUMBER(s)
AFOSR-81-0142

9. PERFORMING ORGANIZATION NAME AND ADDRESS
DEPARTMENT OF ENGINEERING SCIENCE & MECHANICS
VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY
BLACKSBURG, VA 24061

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
61102F
2307 B1

11. CONTROLLING OFFICE NAME AND ADDRESS
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH/NA
BOLLING AFB, DC 20332

12. REPORT DATE
July 1982

13. NUMBER OF PAGES
8

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DTIC ELECTE JAN 7 1983 S D B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

ANGLE-PLY
COMPOSITE MATERIALS
CLOSE-FORM SOLUTIONS
LAMINATES
PLATES
RECTANGULAR PLATES
TRANSIENT ANALYSIS
TRANSVERSE SHEAR DEFORMATION
TRANSVERSE IMPULSIVE LOADING

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The technical objectives of the research performed, technical approach utilized and progress made on the research sponsored is described. Technical papers published or accepted for publication are also listed.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD A123182

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ANNUAL REPORT

ON

NONLINEAR TRANSIENT ANALYSIS OF LAYERED COMPOSITE PLATES

(Grant AFOSR-81-0142)

Submitted to

STRUCTURAL MECHANICS SECTION
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Bolling Air Force Base, Washington, D.C. 20332

by

J. N. Reddy
Department of Engineering Science and Mechanics
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

July 1982

1. (a) Title of Research

Nonlinear Transient Analysis of Layered Composite Plates

(b) Principal Investigator

Professor J. N. Reddy

2. (a) Key Words

Analysis, classical	Materials, composite
Analysis, finite-element	Materials, fiber-reinforced
Analysis, nonlinear (geometric)	Structures, laminated
Analysis, transient	Structures, plate
Analysis, vibration (free oscillations)	

(b) Technical Objective (Phase I: First-Year)

1. To develop a finite-element analysis for nonlinear transient response of laminated, anisotropic composite plate structures constructed of fiber-reinforced, filamentary composite materials.
2. To assess the accuracy of the analysis by comparison of numerical results for problems that are amenable to exact-form of solutions, and provide bench mark results for future investigators.

3. Approach Utilized in Research Completed (Phase I)

The approach used in Phase I (plates) research is two-fold:

1) the development of nonlinear (in the von Karman sense) transient analysis capability by the finite element method for layered composite paltes

2) Classical (spatial) solutions for special cases of plate geometry, loading, boundary conditions, and lamination scheme.

4. Summary of Progress Made in Phase I Research

Forced motions of laminated composite plates are investigated using a finite element that accounts for the transverse shear strains, rotary inertia, and large rotations (in the von Karman sense). The present results when specialized for isotropic plates are found to be in good agreement with those available in the literature. For two different lamination schemes, under appropriate boundary conditions and sinusoidal distribution of the transverse load, the exact form of the spatial variation of the solution is obtained, and the problem is reduced to the solution of a system of ordinary differential equations in time, which are integrated numerically using Newmark's direct integration method. Numerical results for deflections and stresses are presented showing the effect of plate side-to-thickness ratio, aspect ratio, material orthotropy, and lamination shceme. Although the results obtained are for certain geometries, loadings, lamination scheme, and material properties, it should be pointed out that the element developed herein can be employed to laminated plates of arbitrary geoemtry, lamination scheme, material properties, boundary conditions, and loading (only limitations are those assumed in the laminated plate theory). The present analysis does not account for material damping effects.

5. Technological Significance and Relevance to the Air Force.

The results obtained in this research should be of interest to composite-structure (and aircraft) designers, and to experimentalists and numerical analysts in verifying their results. Research in the following categories, among others, of systems of

engineering interest is expected to benefit from the results of this research.

(1) Cord-reinforced rubber skirts for air-cushion vehicles

(2) Cord-reinforced rubber tires and belts

(3) Filament-wound shell structures, such as rocket-motor casings, deep-diving submersibles, piping, and other pressure vessels

(4) Wire-reinforced solid-propellant rocket grains

(5) Ablative materials, such as quartz-phenolic and carbon-carbon

(6) Aircraft structural components such as wing panels

(7) Concrete and masonry structures undegoing bending

6. Bibliography

This bibliography is limited to technical reports, journal articles and conference papers published, and journal articles and conference papers accepted since the initiation of the Grant in April 1981.

(a) Technical Reports Issued

1. Reddy, J. N., "Analysis of Layered Composite Plates Accounting for Large Deflection and Transverse Shear Strains," Technical Report No. 1 (VPI-E-81.12), May 1981.

2. Reddy, J. N., "On the Solutions to Forced Motions of Layered Composite Plates," Technical Report No. 2 (VPI-E-81.24), September, 1981.

3. Reddy, J. N., "Geometrically Nonlinear Transient Analysis of Laminated Composite Plates," Technical Report No. 3 (VPI-E-82.8), March 1982.

(b) Journal Articles and Conference Papers Published

1. Reddy, J. N. and Chao, W. C., "Nonlinear Oscillations of Laminated, Anisotropic, Rectangular Plates," Journal of Applied Mechanics, Vol. 49, pp. 396-402, 1982 (based on Technical Report No. 1).

2. Reddy, J. N., "Analysis of Layered Composite Plates Accounting for Large Deflections and Transverse Shear Strains," in Recent Advances in Nonlinear Computational Mechanics, edited by E. Hinton, D. R. J. Owen, and C. Taylor, Pineridge Press, Swansea, pp. 155-202, 1982 (based on Technical Report No. 1).

3. Reddy, J. N., "On the Solutions to Forced Motions of Rectangular Composite Plates," Journal of Applied Mechanics, Vol. 49, pp. 403-408, 1982 (based on Technical Report No. 2).

4. Reddy, J. N., "Nonlinear Vibration of Layered Composite Plates Including Transverse Shear and Rotatory Inertia," ASME 18th Vibration Conference, ASME Paper No. 81-DET-144, Hartford, Connecticut, 1981 (based on Technical Report No. 1).

5. Reddy, J. N. and Chao, W. C., "Nonlinear Oscillations of Laminated, Anisotropic, Thick Rectangular Plates," Symposium on Structures and Materials III: Impact and Vibration of Composites and Structures, 1981 ASME Winer Annual Meeting, November 15-20, 1981, Washington, D.C. (based on Technical Report No. 1).

6. Reddy, J. N. and Mook, D. J., "Dynamic (Transient) Analysis of Layered Anisotropic Composite Plates," in Computational Methods and Experimental Measurements, edited by G. A. Keramidas and C. A. Brebbia, Springer-Verlag, New York, pp. 737-748, 1982 (based on Technical Report No. 2).

(c) Journal Articles and Conference Papers Accepted:

1. Reddy, J. N., "Nonlinear Transient Response of Layered Composite Plates," International Conference on Finite Element Methods, August 2-6, 1982, Shanghai, China (based on Technical Report No. 2).

2. Reddy, J. N., "Dynamic (Transient) Analysis of Layered Anisotropic Composite-Material Plates," Int. J. Numer. Meth. Engng, to appear (based on Technical Report No. 2).

3. Reddy, J. N., "Geometrically Nonlinear Transient Analysis of Laminated Composite Plates," AIAA Journal, to appear (based on Technical Report No. 3).

7. Project Personnel

J. N. Reddy, Principal Investigator
J. D. Mook, Graduate Research Assistant (M.S.)
N. S. Putcha, Graduate Research Assistant (Ph.D.)
Richard Tam, Graduate Research Assistant (Ph.D.)

8. Honors and Awards

Professor J. N. Reddy:

* Organized two sessions on recent developments in finite elements at Eleventh Southeastern Conference on Theoretical and Applied Mechanics (SECTAM XI), University of Alabama in Huntsville, Apr. 8-9, 1982.

* Invited to present a paper at a session on nonlinear structural dynamics at the Eleventh Southeastern Conference on Theoretical and Applied Mechanics (SECTAM XI), Huntsville, Alabama, Apr. 8-9, 1982.

* Invited to present a paper at a session on finite elements in fluid flow at the Eleventh Southeastern Conference on Theoretical and Applied Mechanics (SECTAM XI), Huntsville, Alabama, Apr. 8-9, 1982.

* Invited to present a paper at a session on computational strategies for inelastic and nonlinear problems at the ASCE National Convention, New Orleans, LA, Oct. 25-29, 1982.

* Co-authored a book, Advanced Engineering Analysis (with M. L. Rasmussen), published by John Wiley & Sons, New York, 1982.

* Organized a session at the 19th Annual Meeting of the Society of Engineering Science, University of Missouri-Rolla, Oct. 27-29, 1982.

* Invited as a General Lecturer to a Seminar on Mechanics of Materials and Structures, Universitiy of Rome, May 4-7, 1982.

* Invited to present a paper on three-dimensional flows at 10th IMACS World Congress on Systems Simulation and Scientific Computation, August 8-18, 1982, Montreal, Canada.

* Invited to present lectures on the Numerical Simulation of Three-Dimensional Flows at the Joint Institute for Accoustics, Stanford University, February, 1982.

* Invited to present two papers at the 19th Annual Meeting of the Society of Engineering Science, University of Missouri-Rolla, Oct. 27-29, 1982.

* Invited to present a lecture at ARO Workshop on Computational Aspects of Penetration Mechanics, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, April 27-29, 1982.

* Invited to present a 90-minute lecture as part of a University/Industry program at Carnegie-Mellon University, Pittsburg, November 23, 1982.

J. D. Mook:

* Awarded M. S. Degree in Summer 1982.


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